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Armored Medical Research Laboratory

Fort Knox, Kentucky

PROJECT NO. 3 - TOXIC GASES IN ARMORED VEHICLES

Second Partial Report On

SUB-PROJECT NO. 3-9 - Determination of Ventilation Requirements for Gas-Proofing Tanks of the M4 Series.

Project No. 3-9

23 June 1943

ARMORED FORCE MEDICAL RESEARCH LABORATORY
Fort Knox, Kentucky

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1. PROJECT: No. 3 - Toxic Gases in Armored Vehicles. Second Partial Report on Sub-Project No. 3-9 - Determination of Ventilation Requirements for Gas-Proofing Tanks of the M4 Series.

a. Authority - Letter Commanding General, Headquarters Armored Force, Fort Knox, Kentucky, 400.112/6 GNOHD, dated September 24, 1942.

b. Purpose - To determine the basic design requirements of a system of positive-pressure ventilation for the M4A3 tank and the feasibility of installing the necessary equipment in the tank. To investigate the degree of protection against chemical warfare agents obtained by this method of ventilation.

2. DISCUSSION:

a. The use of negative-pressure ventilation and the existence of numerous apertures in the turret and hull of the M4 tank make it highly vulnerable to attack by chemical warfare agents. This vulnerability can be reduced by changing the ventilation to a positive-pressure system and sealing, so far as possible, the openings in the tank. Two advantages are gained: the air is drawn in through a single inlet and can, therefore, be made to pass through a purifying canister; the flow of air through leakage openings is reversed and, if the outward velocity is sufficiently high, the ingress of outside contamination is prevented.

b. The feasibility of the positive-pressure system of ventilation as a means of gas-proofing depends upon the rate of ventilation required to produce the desired pressure and the consequent size of the equipment required and the amount of power consumed. The objectives of this study were to determine the design requirements of the apparatus and to install the equipment in a tank for laboratory and field studies of its performance.

c. The study represents a joint undertaking of the Armored Force Board and the Armored Force Medical Research Laboratory. A detailed description of the equipment, the results of field tests and a discussion of the advantages and limitations of positive-pressure ventilation are presented in the Appendix.

3. CONCLUSIONS:

a. The vulnerability of the M4 tank to attack by chemical agents can be greatly reduced by conversion of the ventilation system to the positive-pressure type with a suitable gas canister in the line and improving the sealing of apertures in the turret and hull.

b. With a positive-pressure of one half inch, water gage, protection is afforded against outside clouds of gas or smoke, contaminated ground, frangible grenades, land mines, airplane spray and small bombs.

c. Added personal protection may be required against large volumes of liquids released on the tank at high velocity from close ambush projectors, airplane bombs, etc.

d. The feasibility of sealing the M4A3 tank and installing the necessary equipment to produce a positive-pressure of one half inch, water gage has been demonstrated. Similar alterations in the M4A2 and M4A4 appear to be possible. Application of this method of protection to the M4A1 requires first the improvement of engine cooling to permit the relocation of the oil coolers in the engine compartment.

e. Installation of the proposed ventilating equipment requires the re-location of the oil cooling radiators and closing off the bulkhead; re-location of the air cleaners; installation of an auxiliary generator of greater capacity, occupation of some space in crew compartment. These factors must receive further consideration and study in relation to the improvement to be gained with respect to gas protection. Consideration of every aspect of the problem is essential from the start since they are all interdependent.

f. The use of positive-pressure ventilation offers other advantages over the negative-pressure system, in addition to reducing the vulnerability of the tank to gas attack:

(1) It provides an independent system of ventilation, designed especially for the crew.

(2) The gun fume problem is largely eliminated.

(3) A considerable degree of dust control is possible.

(4) Opportunity for crew heating in cold weather is greatly enhanced.

(5) Better control over the distribution of air within the tank is possible, thereby improving the situation with respect to cooling in hot climates.

4. RECOMMENDATIONS:

a. That further development of the positive-pressure system of ventilation in tanks of the M4 series be carried out by the Tank and

Automotive Center, Ordnance Department, with immediate consideration being given to the M4A3 model so that the necessary changes can be made rapidly in the event the gas-protection of tanks is needed.

b. That, in this development, full consideration be given from the start to the entire problem, namely, the question of adequate power, re-location of radiators and air cleaners, stowage arrangements to accommodate the additional equipment, etc., as well as the problem of sealing, ventilation rate and other aspects of design of the positive-pressure system.

c. That a pilot model of a modified M4A3 tank be constructed to provide a system of positive-pressure ventilation and canister for gas-protection and incorporating all other necessary changes and that this tank be subjected to further field tests with respect to its mechanical operation, accessibility of parts for maintenance as well as gas-protection.

d. That the Chemical Warfare Service, in cooperation with Ordnance, develop gas canisters of the required efficiency, life, size and other characteristics for use with positive-pressure ventilation in the M4 tanks.

Prepared by:
Lieut. Colonel Theodore F. Hatch, SnC
Major E. W. Hollingsworth, A. F. B.
Lieutenant Robert H. Walpole, F. A.

APPROVED Willard Machle
WILLARD MACHLE
Colonel, Medical Corps,
Commanding.

Frank R. Williams
FRANK WILLIAMS,
Colonel, Armored Force,
Armored Force Board
President

2 Incls:
#1 - Appendix
#2 - Four (4) photographs

APPENDIX

The vulnerability of tanks to attack with chemical warfare agents is generally recognized and has been demonstrated by numerous tests. The ease of penetration of outside contamination into the vehicle results, in part, from the fact that numerous apertures exist in the structure; of greater importance, however, is the method of ventilation which produces an inward air flow through these apertures so that outside contamination is immediately brought into the tank.

The possible methods of dispersion of chemical agents include, in addition to those employed for general contamination, direct application to the tank from various distances. Methods of direct attack have been classified as follows:

1. Short range (ambush weapons): hand grenades and liquid projectors.

2. Medium range: Small arms and AT ammunition carrying suitable gas charges.

3. Long range: Gas shells and low altitude bombs.

Depending upon the method of dispersion, chemical agents may enter the tanks as vapors, in the form of liquid droplets or spray, and as solid particulate matter.

Objectives of gas attack upon tanks include: (a) Immediate or delayed action to produce casualties or death of the crew, (b) temporary incapacitation of the crew to insure the ready destruction of the tank by other weapons and (c) the reduction in efficient use of the vehicle as a result of contamination of inaccessible parts by persistent agents.

For the protection of the tank crew against chemical agents, consideration has been given to the two basic methods: (1) individual protection and (2) protection of the tank as a whole. The first involves the supply of purified air to each crew member either by personal respirator or from a central canister and the use of anti-gas clothing. The second requires effective sealing of the apertures in the hull and turret of the tank and the installation of a positive-pressure system of ventilation for the crew compartment, the air being supplied through a suitable purifying canister.

The present report deals with the preliminary development and tests of a system of positive-pressure ventilation for gas-protection of tanks of the M4 series and a discussion of its merits and limitations.

1. Positive-Pressure requirement.

Since it is assumed that no tank can be made perfectly tight the objective of the positive-pressure system of ventilation is to draw in

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purified air and force it out through all leakage points at a sufficiently high velocity to prevent the ingress of contaminants. Among the various forces which tend to carry chemical agents into a tank against positive-pressure, the wind is the most common and for protection against it, the internal pressure must exceed the velocity pressure of the outside air movement relative to the tank. A pressure of one half inch, water gage, is equivalent to a wind velocity of 30 mph blowing against the stationary tank or a velocity of 15 mph when the vehicle is traveling into the wind at an equal speed. In the present work this pressure has been employed since gas is not likely to be employed at higher wind velocities.

2. Sealing.

The rate of air flow required to develop a positive-pressure of 1/2" within the crew compartment depends upon the completeness of sealing of apertures. It is recognized that some leakage must exist but because of the limited space available for the installation of a gas canister it is essential that the total orifice area through which air escapes be kept at a minimum. In a previous study* the amounts of leakage contributed by the various openings in the hull and turret of an M4 tank were determined. The total air flow, exclusive of leakage through the bulkhead, was found to be approximately 400 cfm. This is obviously more than can be provided through a canister of reasonable size and improvement in sealing was therefore indicated. It was assumed that the apertures around the periscope and the cracks in the hatchways could be sealed practically completely and that the leakage through the gun mounts could be greatly reduced without resorting to elaborate or interfering seals. It was further assumed that all openings in the bulkhead could be closed. These assumptions led to the conclusion that a rate of air flow of less than 200 cfm would be sufficient to produce the required pressure. Accordingly, a ventilating system was designed with an available capacity of 200 cfm through the gas canister and approximately 500 cfm when discharging freely into the crew compartment.

3. Design and installation of ventilating system.

The ventilating system employed in these tests consisted of a No. 5 "Rotoclone" fan, belt-driven by a 24-volt motor, a standard CWS 50 cfm collective canister and the necessary ducts to bring the air in from outside and discharge it either freely or through the canister into the crew compartment. The equipment was installed in an M4A3 tank as shown in Fig. 1. The apparatus fits under the turret basket and in the corner spaces formed by the bulkhead, side walls and turret basket. One of the objectives of this study was to determine the practicability of installing a ventilating system in the tank without utilizing space otherwise employed and the design of the present equipment was conditioned by this specification. The arrange-

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* Project No. 3—Toxic Gases in Tanks. Sub-Project No. 3-9, Partial Report on Ventilation Requirements for Gas-Proofing Tanks of the M4 Series. March 1, 1943.

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chosen is not necessarily the best but the fact that the apparatus was installed without serious interference with regular stowage demonstrates the practical possibility of such a modification in tank ventilation.

It was necessary, at the outset, to remove the engine air cleaners from the crew compartment and the transmission oil radiator from the bulkhead. The new locations of these items in the engine compartment are shown in Fig. 2. These may not be optimum positions but served the purposes of these tests. All openings in the bulkhead were then sealed except the two which normally carry ducts from the air cleaners to the engine; these were employed as air inlets for the ventilating system (See Fig. 1).

Sealing of the apertures in the hull and turret consisted of the following:

a. Bulkhead - all non-essential openings completely closed off; openings for control rods packed with felt gaskets.

b. Hatches - gaskets were improved by the addition of sponge rubber, as needed, to effect practically complete seals.

c. Periscopes - leakage around the periscope housing can be eliminated by means of properly shaped rubber gaskets. In anticipation of this, they were simply caulked in these tests. Minor openings in the rotating mountings were ignored as negligible.

d. Turret Hatch Ring - no sealing required.

e. Turret Ring - leakage reduced by greasing only. While leakage in the present ring is not great, it is believed that it could be reduced with changes in design.

f. 75mm Gun Mount - a flexible gasket was inserted into the peripheral spacing between the opening in the front plate of the turret and the curved surface of the gun mount immediately behind it. The gasket was held in place by a thin metal strip which did not interfere with the movements of the gun. The gasket largely closed off the aperture and an application of heavy grease further improved the situation.

g. Coaxial Machine Gun - an asbestos gasket served to close the annular space around the gun barrel.

h. Bow Machine Gun - a flexible skirt attached at one end to the hull and at the other to the ring on the gun mount effectively sealed this leakage point.

i. Ventilators - the four ventilators were completely sealed by means of rubber gaskets.

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j. Revolver Port -
Caulking was provided to reduce leakage to a minimum since previous tests had shown negligible leakage with well machined and closely fitting parts.

k. Miscellaneous - driver vision slits were completely sealed because of their elimination from later tank models. All bolt holes in the sponson were sealed and openings in welded joints plugged. Some leakage was found at bolted joints such as around the periphery of the 75 mm gun mount front plate and the circumference of the turret ring where it is attached to the hull. The application of a suitable sealing compound before assembling these joints would eliminate the unnecessary leakage.

4. Pressures and Ventilation rates attained.

In the finished tank the following pressures and rates of airflow were obtained in the buttoned-up tank:

a. Through the canister at 170 cfm - - - - - - - - - - 0.4 to 0.5 ins., water gage.

b. Direct discharge at approximately 500 cfm. - - 2.ins., water gage.

The power consumption at the higher rate of ventilation was approximately 3/4 H.P.

RESULTS OF TESTS

Test No. 1. Using chloroacetophenone vapor (tear gas) as the test agent, the tank was exposed in the gas chamber to a heavy atmospheric concentration. An average wind velocity of 10 mph was directed toward the bow of the tank, by means of fans which were located so as to produce maximum velocities at vulnerable points, such as the gun mount. In repeated tests a full crew remained inside the tank half-hour periods without gas masks being worn and without the slightest suggestion of inward leakage as determined by lacrimation, respiratory or skin irritation or by smell.

Test No. 2. In this series of tests, tear gas smoke was disseminated from six pots attached directly to the tank, two mounted on the deck directly under the 75 mm gun and two fixed on each bow fender. The high concentrations and relative distribution of the smoke about the tank are shown in Figs. 3 and 4. By this means it was possible to drive the buttoned-up tank for test periods of approximately 15 minutes while it was continually enveloped in a cloud of the test agent. Tank speeds up to 20 mph were attained. The canister proved to be incapable of removing completely the particulate smoke and, as a consequence, some lacrimation occurred among the crew, although it was not serious enough to require the use of gas masks. Since the performance of the canister was not under investigation, further tests were conducted with the inlet to the ventilation system extended vertically by means of a stack, to get above the heavy smoke cloud. In this way the concentration of smoke entering the apparatus was reduced to a level which was successfully handled by the canister. In repeated tests with this arrangement and with tear gas

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pots attached to the tank, as described above, the pressure ventilation performed successfully, as indicated by the fact that the crew experienced no eye irritation and did not make use of their gas masks during cross-country tests.

In another series of tests, the tank was driven over an area which had been generally contaminated with liquid tear gas and in addition, tear gas pots were set up at intervals along the driving course. Again, the pressure tank was able to negotiate the area without contamination of the crew compartment.

It is to be noted, of course, that the stack was employed only as an expedient in these tests and is not suggested as part of the apparatus. A canister properly designed for the removal of smoke as well as vapors, is needed.

Test No. 3. The tank was bombed from an altitude of approximately 60 feet, using 1 gallon cans of liquid tear gas. The speed of the airplane was 135 mph, so that the velocity of the container at impact was approximately 200 fps, equal to the free fall from a height of 600 feet. Excellent hits were obtained on the front of the tank and directly under the gun. The test liquid was thrown with considerable velocity up under the gun shield and successfully wetted the entire front of the tank. Bombs loaded with water were also employed during the test and the crew were unable to determine when the change to test bombs occurred. There was no eye irritation or other indication of leakage of gas into the crew compartment during the attack. Gas masks were not donned until the tank was opened up. Shortly after the last hit, some liquid leaked through at the hinge of the driver's hatch and struck the driver's hand. In contrast to the experience in the experimental pressure tank, in a standard M4A3 located beside it, the crew were forced to put on their masks immediately after the first hit occurred, in spite of the fact that neither this nor any of the subsequent hits were on the standard vehicle.

DISCUSSION OF RESULTS

The results of the foregoing tests indicate that a positive-pressure of 0.5", water gage, is sufficient to prevent the ingress of outside clouds of gas, smoke or spray or of dust from contaminated ground. The combination of positive-pressure and improved sealing of apertures is also effective, within limits, in keeping out liquid agents which are released with high velocity from points of impact on the tank itself. In this connection, it must be pointed out that in these tests, the bombs contained only 1 gallon of liquid. In reported British tests, however, in which 5 gallon containers were employed, the M4 tank, along with all others investigated, was found to be vulnerable to such attacks. The test liquid was forced through the apertures and dripped onto the clothing and skin of the occupants. While the British tests were conducted with a standard tank operating with negative-pressure ventilation, it cannot be assumed from our tests that either the sealing or the positive-pressure is adequate to prevent inward leakage where large quantities of liquid are sprayed against the vulnerable areas with high velocity.

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A decision with respect to the use of positive-pressure ventilation should not be based upon considerations of the limitations of the system only. The relative probability of occurrence of the different forms of attack by chemical agents must be considered as well and also, it is necessary to establish definitely the basic purpose of this method of tank protection. With respect to the former, if the chemical agents are to be most frequently encountered in the form of vapors generally dispersed in the air or as ground contaminants then the positive-pressure method has considerable usefulness by itself. On the other hand, if the favored form of attack is to be by airplane bombing or from close ambush, using a high velocity projector, then dependence must also be placed upon the individual protection of the crew.

The second point to be considered is the basic purpose of the positive-pressure system. Should it be provided as the only means of protection and accepted or rejected from this point of view alone, or should it be evaluated as an adjunct to the individual safeguards? If its purpose is to provide complete protection then it must function satisfactorily at all times and against all forms of chemical attack. As pointed out above, the positive-pressure system will not insure complete protection under all conditions. As an adjunct to individual protection, however, it has undoubted merit. It will provide, in a large percentage of cases, complete protection against chemical agents generally disseminated in the air or on the ground, and will greatly reduce the concentration of gas in the tank atmosphere after any type of attack*; thus, the crew are allowed some time to put on their respirators in the event of a surprise attack. Mutual dependence upon tank and personal protection does not add to the equipment to be provided since respirators must be carried in any event, (for crew protection when evacuating the tank in a contaminated area). A disadvantage of the joint use of the two systems is that it may result in confusion with resulting failure to put on respirators when necessary. This, however, could be taken care of by proper training, once the doctrine of use has been definitely established. The advantages and disadvantages of the system cannot be evaluated fully until more extensive field tests have been conducted, preferably with chemical warfare agents, under operating conditions which simulate closely actual attacks.

Such field tests are also needed in order to determine the design rerquirements of the canister. A principal objection to the positive-pressure system in previous considerations of the method has been the excessive size of the proposed canister. It has been assumed that the life of this element should be equal to that of the canister in the individual respirator. Owing to space limitations in the tank the resulting canister may be too large and, in that event, it will be necessary to review the situation and determine the degree of compromise that is permitted. Since the mobility of the tank is much higher than is that of foot troops, it can pass through a contaminated area more rapidly. Owing to this reduced period of exposure, it may be proper to use a shorter-lived canister. On the other hand, the more concentrated local attack which is possible on tanks may result in the development of higher concentrations of chemical agents. These and other factors must be considered in determining the canister design rather than simply making use

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* Except penetration of gas charged shells into the crew compartment.

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of design experience which is based upon quite different field situations. For most efficient use of the space which is available the total canister capacity may be provided by a number of units built to fit the spaces rather than to make use of a single element.

Other Advantages of Positive-Pressure Ventilation.

In previous reports* the advantages of positive-pressure ventilation, as contrasted with the present system of negative-pressure ventilation, were pointed out. In addition to the degree of gas protection which is provided, the method makes possible the practical elimination of the dust problem in buttoned-up tanks and, because of the reversal of direction of air flow it greatly lessens the dust nuisance when driving an open tank. By means of a positive pressure of 1/2 inch or more, the contamination of the crew compartment atmosphere with gun fumes is reduced to levels well below the upper safe limit and no further control of this hazard is required. With respect to tank heating, a positive-pressure system of ventilation has the great advantage that it eliminates high velocity drafts of cold air which are created in present tanks and also allows direct heating and distribution of the incoming air.

In connection with crew cooling, the method has certain limitations. The ventilation rate in the standard M4A3 tank varies from 500 cfm at idling engine speed up to approximately 2500 cfm at cruising speed. In contrast, the rate provided with the experimental positive-pressure system are 170 cfm during gas protection and 500 cfm at other times. Laboratory tests and calculations of heat loads** show that with a rate of ventilation of 170 cfm the increments of heat and moisture aided by solar radiation and evaporation of sweat from the crew will result in the building up of extreme temperature and humidity within the tank when the temperature and moisture content of the outside air are high. It must be accepted, therefore, that if the tank is forced to operate for a period of hours in a gas-contaminated area and in a hot and moist climate, the tank atmosphere will become intolerable. The importance of this must be assessed in terms of the likelihood of occurrence of such a combination of circumstances. One possible method of individual cooling which may be applicable has been investigated***.

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* Project No. 3 - Toxic Gases in Armored Vehicles. First Partial Report on Sub-Project No. 3 - 4 -- Determination of Basic Ventilation Characteristics of Tanks of the M4 Series. Sub-Project No. 3 - 6 -- Determination of Basic Ventilation Characteristics of Tanks of the M5 Series. April 26, 1943.

** Report on Physiological Characteristics of T23 Tank., June 5, 1943.

*** Project No. 2 - High Temperatures in Tanks. Final Report on Sub-Project No. 2 - 28 -- Test of Individual Crew Conditioning System.

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Even the higher rate of ventilation of 500 cfm is not wholly adequate for all situations. The ventilation rate for general operation, however, is limited only by the power and space available. It is understood that a system of positive-pressure ventilation is at present under development by the Tank and Automotive Center which contemplates a ventilating capacity of 1200 cfm for general operation. This should be adequate, provided the heat load from the transmission and final drive is reduced.

Installation of the ventilating equipment in the M4A3 tank appears to offer no insurmountable difficulties. With respect to the M4A1, however, it is understood that because of the present limitations in engine cooling, removal of the two bulkhead radiators into the engine compartment is not a simple matter. Further improvement of engine cooling may alter this situation.

The present location of the apparatus as employed in the experimental tank will not be possible with the contemplated rearrangement of ammunition stowage. There should be no difficulty, however, in placing it in part on one or the other sponson.

Summary of Position With Respect to Positive-Pressure Ventilation.

1. The relative vulnerability of the M4 tank to attack by chemical warfare agents is greatly reduced by conversion of the ventilating system to the positive-pressure type with the attendant sealing of apertures and use of an air-purifying canister. Tests have indicated that with a positive-pressure of one half inch, a high degree of protection is obtained against: (a) Outside clouds of gas; (b) the vapor and dust given off from contaminated ground; (c) frangible grenades; (d) land mines; (e) liquids splashed onto the tank at low velocities; (f) spray; (g) small liquid bombs.

2. In addition, conversion of the ventilation to the positive-pressure type provides an independent system which can be designed and operated for the benefits of the crew alone (in contrast to the present arrangement in which the crew compartment ventilation is merely a by-product of the engine ventilation). Thus, it becomes possible to reduce the dust nuisance, provide better heating in the winter and cooling in the summer. Furthermore, the problem of gun fumes is largely eliminated.

3. An independent system of positive-pressure ventilation appears to be the method of choice and should be employed unless it interferes seriously with other functions of the tank. The cost of installing positive-pressure ventilation in terms of power and space requirements and necessary rearrangement of oil radiators, engine air cleaners and other equipment must be carefully weighed against the benefits to be derived from the change.

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4. It is recognized that the installation of a system of positive-pressure ventilation requires certain changes in other tank equipment and that the feasibility of making such changes cannot be determined without considerable study. It is clear, for example, that an auxiliary generator of greater capacity is required. The ventilating equipment will occupy a certain amount of space in the crew compartment and stowage may have to be altered somewhat. The functioning of oil cooling radiators in the engine compartment and the question of their interference with engine cooling must receive further investigation. The operation of the air cleaners in new locations must also be studied.

This overall development will require time. It is therefore desirable that the entire problem be pursued actively to obtain a definite answer as to the overall feasibility of the proposed change so that the necessary alterations can be made rapidly if and when the need for gas-protection of the tank itself becomes evident. The development program should include, from the start, a consideration of every aspect of the problem since they are all interdependent. Otherwise, serious limitations may be encountered after considerable development work has been done which will jeopardize the whole program.

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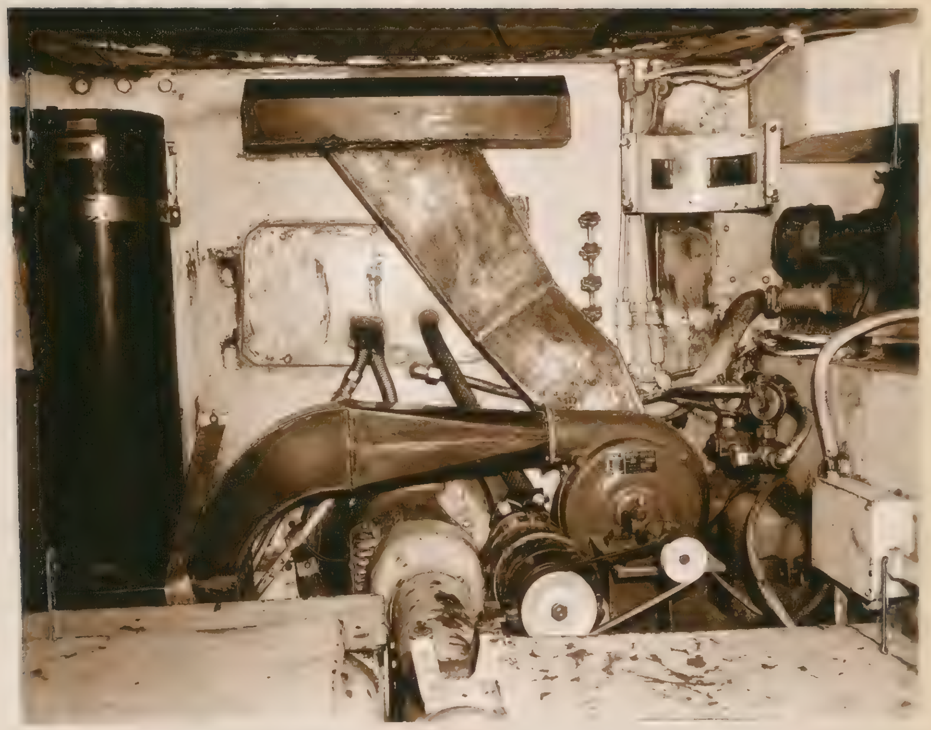

Figure 1

Installation of fan, inlet and discharge ducts and gas canister in crew compartment of M4A3 Tank.

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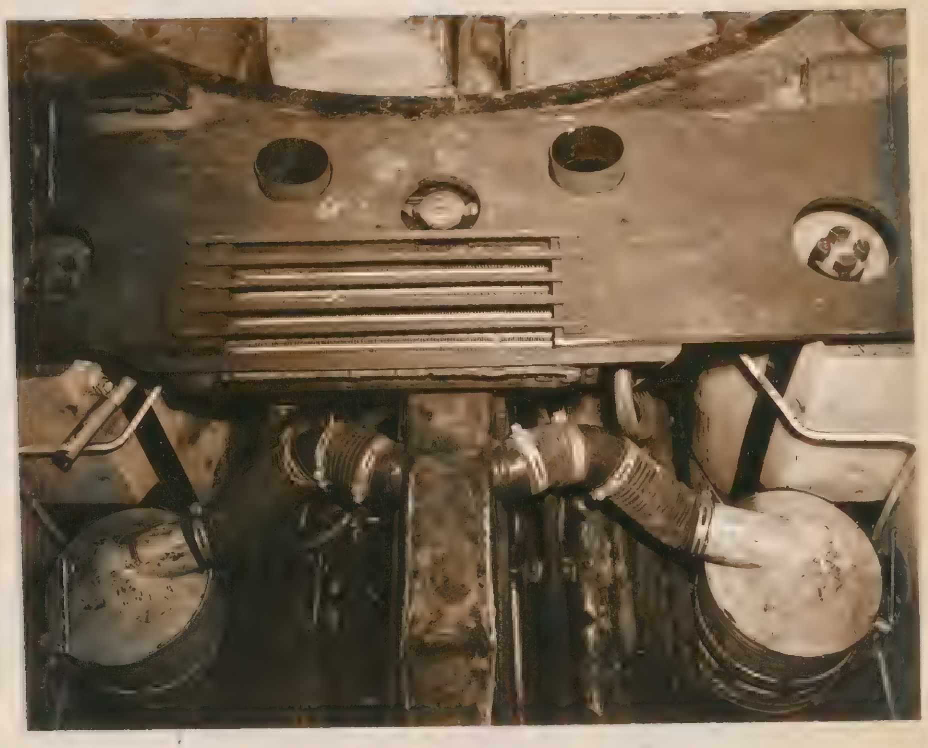

Figure 2

Relocation of oil cooling radiator and air cleaners in engine compartment.

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Figure 3

Field test of experimental pressure tank with six tear gas pots attached to tank. Start of test.

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Figure 4

Field test of experimental pressure tank with six tear gas pots attached to tank. Driving on range.

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